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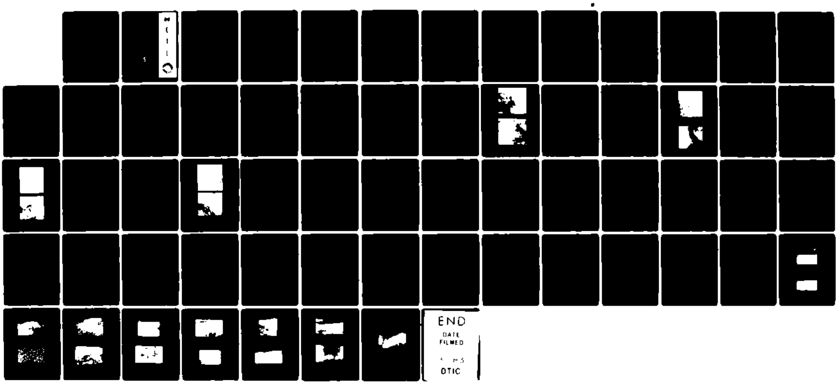

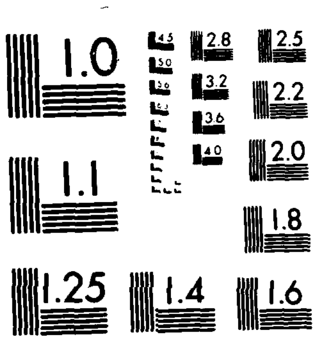


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# Vegetation and terrain effects on digital classification of LANDSAT imagery

Melvin B. Satterwhite

DECEMBER 1982





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LANDSAT scenes from the northern Chihuahuan Desert, south-central New Mexico and western Texas, taken in March and August 1975, were analyzed using conventional supervised digital image analysis techniques. The study objective was to evaluate the digitally classified LANDSAT image against known ground condition and determine those vegetative and terrain factors that could aid the manual interpretation of the classified image. The interpretation of the image and correct classification of most areas were greatly assisted by knowledge of plant community-landform relations, the species phenological and

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physiognomic characteristics, and the reflectance-cover relationsions for the soil and vegetation conditions in each scene.

## SUMMARY

A general classification of land use/land cover can be readily achieved from LANDSAT data by using digital supervised classification techniques. The resultant map, however, often clusters different land cover conditions into the same class. The objective of this study is to evaluate a digitally classified LANDSAT image, and determine those vegetative and terrain factors that could aid in the manual interpretation of the classified image and improve the interpretation by explaining the reasons for some of the misclassification of land cover conditions.

LANDSAT scenes from the northern Chihuahuan Desert, south-central New Mexico, and western Texas, taken in March and August 1975, were analyzed using conventional supervised digital image analysis techniques. The classified images were compared with a ground truth data base that describes the landform and land cover conditions.

Land cover units associated with the major landform conditions were readily classified to level 3 and at times to level 4 with reasonable accuracy. The level 4 classification could not be achieved in all areas because of (1) the similar spectral signatures of some of the land cover classes, (2) the narrow brightness range in various bands of the LANDSAT image, and (3) the small scale of the LANDSAT image. Misclassification occurred more often when different land cover units occurred on the same major landform unit. Factors causing some of the misclassifications were (1) the species composition and the species role in different land cover units; (2) differences in vegetative cover, particularly in those land cover units with either a sparse or very dense cover; (3) the lack of characterizing spectral signatures from the dominant plant species; and (4) the signature of the surficial materials, i.e. gravel-covered surfaces were often spectrally similar to the bedrock from which they were derived.

The interpretation of the classified LANDSAT image and the correct classification of most areas was greatly assisted by knowledge of (1) plant community-landform relationships, (2) the species phenological and physiognomic characteristics, and (3) the reflectance-cover relationships.

## PREFACE

The work reported was done under DA project 4A161102B52C, Task C, Work Unit 0010, "Indicators of Terrain Conditions."

The work was performed during 1979 to 1980 under the supervision of Dr. J. N. Rinker, Team Leader, Center for Remote Sensing and Mr. M. Crowell, Jr., Director, Research Institute.

The author wishes to express his appreciation to the Director, CSL for use of the Digital Image Analysis Laboratory (DIAL) facilities, and to Messrs. W. C. Rice and J. S. Shipman, IBM, for their technical assistance.

COL Edward K. Wintz, CE was Commander and Director, and Mr. Robert P. Macchia was Technical Director of the Engineer Topographic Laboratories during the report preparation.

## CONTENTS

## ILLUSTRATIONS

## TABLES

## VEGETATION AND TERRAIN EFFECTS ON DIGITAL CLASSIFICATION OF LANDSAT IMAGERY

### INTRODUCTION

Numerous investigators have evaluated LANDSAT multispectral scanner digital data for mapping and inventorying forest and rangeland resources. The resultant land cover maps usually depict rather broad categories classified to a level 2 of the Anderson system.[1] Spectral similarities between land cover units and the image resolution have limited the further differentiation of the level 2 classification. The accurate cover classification in arid to semi-arid regions is further limited by the range in brightness levels in the LANDSAT bands and by the similarity of the signatures associated with the land cover units. Frequently, different plant communities have similar spectral signatures and are classified accordingly as the same spectral class. A higher level of classification can be done if an understanding of plant phenological characteristics and plant habit requirements can be incorporated with the digital image analysis and evaluation process.

Previous field and laboratory studies have described the relation between land cover and landform characteristics using medium scale aerial photography.[2] In addition, the relations between cover, soil and plant reflectance in the four LANDSAT bands have been related to the percent cover of the soil-vegetation targets.[3] The findings of these studies, together with our understanding of the vegetation phenological characteristics, suggest that a better classification of LANDSAT data can be accomplished. The approach of this study was to integrate the land cover and landform associations, and the plant phenological and reflectance characteristics, with the supervised digital classification techniques.

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[1]J. R. Anderson, et al., 1967. "A Land Use and Land Cover Classification System for Use with Remote Sensor Data." U.S. Geological Survey; Professional Paper 964.

[2]Melvin B. Satterwhite and J. Ehlen, 1980. Vegetation and Terrain Relationships in South-Central New Mexico and Western Texas, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA. Report, ETL-0245. November 1980, AD-A095 159.

[3]Melvin B. Satterwhite, 1981. "Changes in Soil Spectral Reflectance by Vegetative Cover." Proceedings ASP-ACSM Convention 1981. Washington, D.C., pp. 70-86.

**A. Study Objective.** The purpose of this study is to determine those vegetative and terrain factors that could improve land cover classifications on a supervised digital classification of LANDSAT imagery of an arid to semi-arid environment.

**B. Study Area.** The study area is located in south-central New Mexico and western Texas (figure 1). The land use of this area is principally rangeland. Shrub communities dominated by *Prosopis glandulosa*, *Larrea tridentata*, *Flourensia cernua*, and *Artemisia filifolia* are the major land cover, although sizable grasslands dominated by *Bouteloua eriopoda*, *B. curtipendula*, *B. gracilis*, and *Sporobolus flexuosus* are also present.

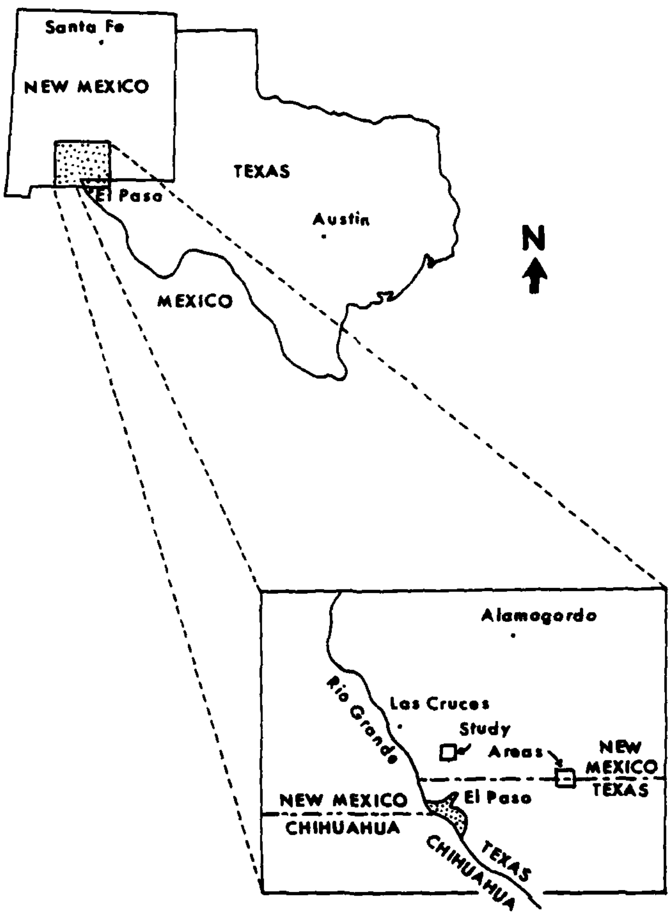


**Figure 1. Location Map of the Study Area**

The landforms and land-use/land-cover conditions in this portion of the northern Chihuahuan desert were studied previously.[4]

The land-use/land-cover conditions for the study area are primarily rangeland (level 1), which is divisible into two sub-units, shrublands and grasslands (level 2). Satterwhite and Ehlen,[5] having modified the Anderson land-use/land-cover system, identified species-dominated communities, at level 3 and 4, using medium scale panchromatic photography and field data.

## MATERIALS AND METHODS

Classifying LANDSAT data for the study area is based on a maximum likelihood algorithm that maximizes the proportion of correctly assigned observations when the data can be represented by multivariate normal distributions. This algorithm is a supervised, parametric classification technique that requires a class mean vector ( $\mu_K$ ) and covariance matrix ( $\Sigma_K$ ) for each class. In this algorithm, an observation vector is classified into the class with the smallest value of

$$L_K\,(x) = \log |\Sigma_K| + (x - \mu_K)^T\, \Sigma_K^{-1}(x - \mu_K) - 2 \log p_K \qquad (1)$$

where

$|\Sigma_K|$ = determinant of covariance matrix for kth class
$\mu_K$ = mean vector for kth class
$\Sigma_K$ = covariance matrix for kth class
$p_K$ = a priori probability
$L_K$ = likelihood function

[4]Melvin B. Satterwhite and J. Ehlen, 1980. Vegetation and Terrain Relationships in South-Central New Mexico and Western Texas, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA. Report, ETL-0245, November 1980. AD-A095 159.

[5]Ibid

Ground areas of homogenous land cover and landform conditions were identified through field and laboratory study, independent of the digital imagery. The ground truth data base used for field definition and class identification consisted of the landform and land cover data and maps reported previously.[6] The corresponding areas in the digital imagery provided the spectral signatures for the classes of interest. The digital classification programs were developed by Rice for ETL's Digital Image Analysis Laboratory (DIAL).[7,8] The first step of the analysis was the delineation of the study area on each of the two LANDSAT images; number 2059-16590, dated 22 March 1975, and number 2221-16575, dated 31 August 1975. The 4-channel composite images and the image of the four LANDSAT spectral bands — 4, 5, 6, and 7 — were stored as images S1AB, S1AB4S, S1AB5S, S1AB6S, and S1AB7S for the August scene and as S2AB, S2AB4S, S2AB5S, S2AB6S, and S2AB7S for the March Scene.

Two regions were identified within the larger study area for detailed evaluation. The Meyer region is in the eastern part of the study area and the Dona Ana, in the western part (figure 1). The nomenclature for the training fields was a short alphanumeric label based on the land cover symbols from the ground truth data base. The nomenclature was indicative of the replicate field or class in the LANDSAT subimage. For example, training field 20-4 represented the 4th replicate for the land cover unit number 20, Larrea tridentata-grass. This procedure satisfied the nomenclature requirement of the classification program and kept an accounting of the training fields created for each land cover unit. With this naming convention, the field/class files to classify the two scenes could be built up interactively. The definition of training fields for the classification process was a highly selective and interactive process. To achieve a good statistical representation of the spectral signature of the

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[6]Melvin B. Satterwhite and J. Ehlen, 1980. Vegetation and Terrain Relationships in South-Central New Mexico and Western Texas, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA. Report, ETL-0245, November 1980. AD-A095 159.

[7]W. C. Rice, J. S. Shipman, and R. J. Speiler, 1978. Interactive Digital Image Processing Investigation, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA. Report ETL-0172, December 1978, AD-A076 342.

[8]W. C. Rice, J. S. Shipman, and R. J. Speiler, 1978. Interactive Digital Image Processing Investigation, Phase II. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA. Report ETL-0221, April 1980, AD-A087 518.

land cover, the author identified two or more training fields, each composed of 100 or more pixels, for each large land cover unit. Training fields representing the smaller land cover mapping units often contained fewer than 100 pixels. Each training field was positioned within a land cover unit determined by visual comparison with the ground truth data base.

A class was created from each training field. Each class was composed of a collection of pixel intensity vectors (bands 4, 5, 6, and 7) interior to the training field. The mean vector and covariance matrix were calculated in order to develop the spectral signature representative of the land cover unit in which the training field was placed. Class spectral signatures were first evaluated for uniformity. Those signatures having a standard deviation of less than 3 in all bands were considered to be representative of a homogenous land cover mapping unit. For all class spectral signatures, a pairwise Bhattacharyya distance between the signatures was computed. As a guide, a Bhattacharyya distance of 0.3 was taken as the value that separated similar classes (0.3) from dissimilar classes (< 0.3). In those cases where several class spectral signatures were similar, they were combined into a single class. When two separate training fields thought to contain the same material led to distinctly dissimilar classes, both classes were initially retained, and the maximum likelihood classification process was used to clarify the situation. Furthermore, the classes created in each study region were only used to classify the region in which they were defined. For this study, a spectral class representing each land cover unit in the ground truth data base was attempted.

The Meyer and Dona Ana regions were classified by the maximum likelihood classification method (MAXLIK P. M.), using the classes created in each region. The homogeneity of each spectral class was measured by the percentages of the pixels of the associated training fields classified to its associated class. A threshold value of 70 percent of the pixels correctly classified was required to consider the class representative of a homogenous land cover unit. Several iterations of the class formation and class selection process were required to derive an acceptable set of classes for each region.

The same training fields in the Dona Ana region were used to classify the March and August scenes. Because a full registration was not practical, the March scene was translated to the August scene by identifying and registering the same features in both images.

The class mean signatures in the four LANDSAT bands were compared for possible vegetative phenological differences that could enable a more accurate determination to be made of the associated terrain conditions. The cool season species would have maximum growth during the early spring or late fall. The warm season species would have maximum growth during the summer and early fall. Depending upon the vegetation's spectral characteristics and the percent cover, the vegetative cover should change the class signature so that differences between the class signatures could be associated with the periods of maximum vegetative growth in comparison with the periods of dormant vegetative cover. Differences in the class spectral characteristics can also result from other factors, e.g. atmospheric or soil moisture. Because of the short time period between the March and August scenes, a significant change in the dominant species composition of the land cover units was not a causative factor. The vegetation index was calculated for each class using the class mean pixel intensity and Equation 2.[9]

$$VI = (MSS\ 7 - MSS\ 5) / (MSS\ 7 + MSS\ 5) \qquad (2)$$

Color composite images of each LANDSAT scene were created by assigning blue color to band 4, green to band 5, and red to band 7.

## RESULTS

The classification of the March and August composite images was shortened by classifying two small areas, the Meyer and Dona Ana regions, which were representative of the terrain and vegetation conditions in the study area. Because of the narrow brightness range in each band, all of the different land cover conditions in the scenes could not be separated. Bands 4 and 7 had a pixel range of 30 units, and bands 5 and 6 had a range of 75 units (appendix A). Hence, each of the 19 land cover units in the Meyer region would have to differ from each other by 1.0 to 1.5 brightness levels in bands 4 and 7 and by about 4 brightness levels in bands 5 and 6 for each land cover unit to be differentiated on the LANDSAT image. This level was not much more specific than the variation, i.e. $< 3.0$ standard deviation, for the various classes representing these land cover units.

[9] C. J. Tucker, 1979. "Red and Photographic Infrared Linear Combinations for Monitoring Vegetation." Remote Sensing of Environment 8:127-150.

### A. Image-Supervised Classification.

**1. Meyer Region.** This region is located on the eastern side of the LANDSAT image. The region is about 340 pixels horizontally and about 359 lines vertically. The labeled polygons that define the training fields for the March scene are shown in figure 2 and for the August scene, in figure 4. The signatures of these classes used in the maximum likelihood classification (MAXLIK) of the March and August scenes are shown in appendix B. Some land cover units that were recognized from the ground truth data were too small to be identified on the LANDSAT image; whereas, other land cover units with similar signatures were grouped into one spectral class. Eight spectral classes were created that represented the 19 land cover units in this region. The land cover units selected for the supervised digital classification were *Scleropogon brevifolious-Hilaria mutica* (10C), *Sporobolus flexuosus-S. cryptandrus* (10D), *Bouteloua curtipendula-Parthenium incanum* (16), *Larrea tridentata* (20), *Larrea tridentata*-grass (21), *Prosopis glandulosa-Atriplex canescens-Xanthocephalum Sarothrae*-grass (50), *Artemisia filifolia*-grass (60), and bare rock (90).

The color-enhanced classified LANDSAT image for the March scene is shown in figure 3 with the 21 training fields delineated. Results of the maximum likelihood classification of the fields are summarized in table 1. The classification was to level 3 among the shrub-dominated communities and to level 4 among the grassland and some shrub communities. The land cover classification, level 3/4, was possible, in part, from prior knowledge of land cover and landform associations. Even so, classes representative of the different land cover units, but occurring on similar landform and soil conditions, were often confused with each other.

The maximum likelihood classification (MAXLIK) of the training fields is summarized in tables 1 and 2 for the eight classes. These data show that the pixels of some training fields were classified into several classes representing different land cover conditions. The spectral uniqueness of a land cover unit as represented by a spectral class is indicated by the classification of the training field's pixels. Misclassification of the field class can be seen in the classification of replicated fields for some land cover units. For example, field/class 16-1 had pixels classified in classes 16, 20, and 21.

The color-enhanced classified LANDSAT image for the August scene is shown in figure 5, with the 19 fields associated with the land cover classes. Results of the maximum likelihood classification of the training fields are summarized in table 2. The level of land cover classification was level 3 for most shrub communities and level 4 for some grasslands and shrub communities.

The results of the digital classification of both the March and August scenes are very similar. For both scenes, the confusion recognized on the classified image was between the spectral classes representing the land cover that occurred on the same major landform unit; basin, alluvial fan and wash, or mountain/hills. Classes on the alluvial fans and the mountain/hills landform units were frequently confused with each other, but less frequently confused with classes in the basin.

a. **Basin Area.** The land cover of the basin area was comprised of grass, shrub, grass-shrub, and shrub-grass communities, dominated by Prosopis glandulosa or Artemisia filifolia shrubs or Sporobolus flexuosus and S. cryptandrus grasses. These species formed several land cover units, 10D, 14, 15, 50, 51, 52, 60 and 62, by their association with each other as either the dominant or subdominant species.

The major land cover class is the Prosopis glandulosa-Atriplex canescens-Xanthocephalum Sarothrae-grass community (50). The smaller important land cover classes are Sporobolus flexuosus-S. cryptandrus grassland (10D) and Artemisia filifolia-Sporobolus flexuosus communities (60). The color-enhanced classification maps for the March and August scenes show these three land cover units. Some confusion was encountered between some areas of the 60 and 10D land cover classes.

The March scene shows less grassland (10D) and more Artemisia filifolia-grass, whereas, the August scene shows more grassland (10D) and less Artemisia filifolia-grass (60) in the basin. Ground photography of these communities is shown in figures D1 and D2.

The supervised classification of the two scenes did not differentiate the other grass-shrub and shrub-grass units in the basin. The species of these land cover units were the same as those in the recognized classes, 10D, 50, and 60; but the species role in these communities varied. For instance, P. glandulosa was the dominant species in land cover unit 50, but only a subdominant species in land cover unit 61. The differentiation of these land cover units on the LANDSAT image was limited by the similar class signature brought about by either a dense cover or a high percent of soil surface. The shrub and grass communities with a dense cover, usually grasses, had a less bright and similar spectral signatures, which make them inseparable on the LANDSAT image. Thus, the Artemisia filifolia-grass (60), Prosopis glandulosa-A. filifolia-grass (51), Sporobolus flexuosus-P. glandulosa (14), Sporobolus flexuosus-A. filifolia (15) and A. filifolia-P. glandulosa-grass (61) communities were frequently misclassified. Land cover units with sparse cover, such as Prosopis glandulosa-Atriplex canescens-Xanthocephalum Sarothrae-grass (50), often had a distinct spectral signature. Much of the class signature in the communities with sparse cover was from the soil with vegetation having only a modifying effect.

**Table 1. Summary of spectral classes and maximum likelihood classification of the training fields for the Meyer Region, March scene**

| SPECTRAL CLASS | COLOR | TRAINING FIELDS* |
|---|---|---|
| 10(C) | Red | (10C-2), (10C-3), 21-7 |
| 10(D) | Green | (10D-2), (10D-3), 60-2 |
| 16 | Gold | (16-3), 16-2, 20-3, 90-2 |
| 20 | Blue | 20-2, 21-1, 21-6, (21-7) |
| 21 | Buff | (21-4), 10C-2, 10C-3, 20-2, 21-1, 16-2, 16-3, 20-3, 21-6 |
| 50 | Brown | (50-3), (50-4), 60-2, 50-5 |
| 60 | Yellow | (60-3), 50-4, 60-2, 50-5 |
| 90 | Purple | 16-2, 16-3, 90-2 |

*Training fields listed have ≥ 10% of the field's pixels classified in the class shown. Fields enclosed in ( ) have ≥ 70 % and those enclosed by (__) have ≥ 90% of the pixels classified to the class shown.

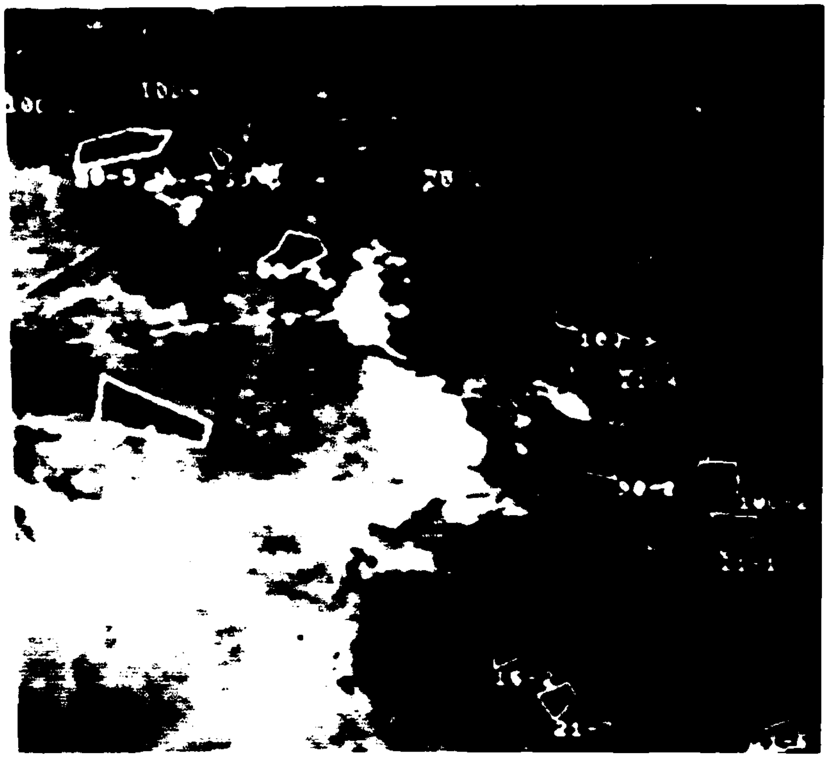

Figure 2. False Color Composite LANDSAT Image, Meyer Region, March Scene

Figure 3. Color Enhanced Classified LANDSAT Image, Meyer Region, March Scene
Numbered polygons correspond to those in Figure 2

**b. Alluvial Fans and Washes.** The land cover on the alluvial
fans and washes in the Meyer region was primarily shrub and shrub-grass
communities, with some grass and grass-shrub communities. The major shrub
species were *Larrea tridentata*, *Acacia constricta*, and *Flourensia cernua*.
The major grass species were *Hilaria mutica* and *Scleropogon brevifolius*,
with *Muhlenbergia arenacea* and *M. porteri* as understory species in some
shrub-grass communities. The dominant species on the fans and some wash
areas was *Larrea tridentata*, whereas, *Flourensia cernua* shrubs and the
grass species *S. brevifolius*, and *H. mutica* dominate sizable areas in many
of the washes and lower fans (figures D8 and D9). *Prosopis glandulosa* was
5 an associate species in some *Larrea tridentata* and *Flourensia cernua*-grass
communities on the intermediate and lower alluvial fans. *A. constricta*
communities (30) occurred on the upper alluvial fans adjacent to the
dissected limestone mountain/hills.

The major land cover classes were the *Larrea tridentata*-grass (21) and *L. tridentata* (20) communities. The smaller important land cover units were *F. cernua*-grass and *Scleropogon brevifolius-Hilaria mutica*, which were grouped into spectral class 10C because of their similar spectral signatures. The distribution of these land cover units on the digitally classified image often differed from their distribution on the ground truth data base. This difference was, in part, a result of the large percentage of bare soil and rock or dense grass cover in some land cover units recognized on the ground (see figures D10 through D15). The gravels on the upper alluvial fans were derived from the limestone hills and were spectrally similar to the parent materials. The soils of the lower fans were mostly fine textured silts and clays, and were highly reflective. The soil signatures and the sparse vegetative cover of these land cover units caused some land cover units to have similar spectral signatures. The ground truth data show the plant communities on these areas were *Scleropogon brevifolius-Hilaria mutica* (10C), *F. cernua*-grass (40), *L. tridentata* (20), *L. tridentata*-grass (21) and *Acacia constricta*-grass (30).

Spectral class 21 corresponds with the intermediate and lower alluvial fans and to the lighter toned portions of the wash landform. *Larrea tridentata* was the dominant species in these areas. The dark-toned areas of the alluvial fans and washes on the March color composite image and the red tones on the March image indicated changes in vegetative conditions. Species in these areas included *Flourensia cernua* and *Larrea tridentata* shrubs, but the grasses *Hilaria mutica* and *S. brevifolius* formed the major portion of the vegetative cover (figures D8 and D9).

**Table 2. Summary of spectral classes and maximum likelihood classification of the training fields for the Meyer Region, August Scene**

| SPECTRAL CLASS | COLOR | TRAINING FIELDS* |
|---|---|---|
| 10(C) | Red | (10C-1), (10C-2), 52-1 |
| 10(D) | Green | (10D-1), 60-1, 15-1, (14-1), 60-2, 52-1 |
| 16 | Gold | (16-1), 16-2, 21-3, 21-4, 10C-2, 16-3, 30-1, 30-2 |
| 20 | Blue | (20-1), (21-5), 21-3, 60-2, 16-3, (21-1) |
| 21 | Buff | 21-3, 21-4, 16-1, 16-2, (30-1), (30-2) |
| 50 | Brown | (50-1), (50-2), 60-2 |
| 60 | Yellow | (60-1), 15-1, 14-1, 52-1, 10D-1 |
| 90 | Purple | (90-1), 21-3, 21-4, 16-3 |

*Training fields listed have $\geq$ 10% of the field's pixels classified in the spectral class shown. Fields enclosed in ( ) have $\geq$ 0 % and those enclosed by (___) have $\geq$ 90% of the pixels classified to the class shown.

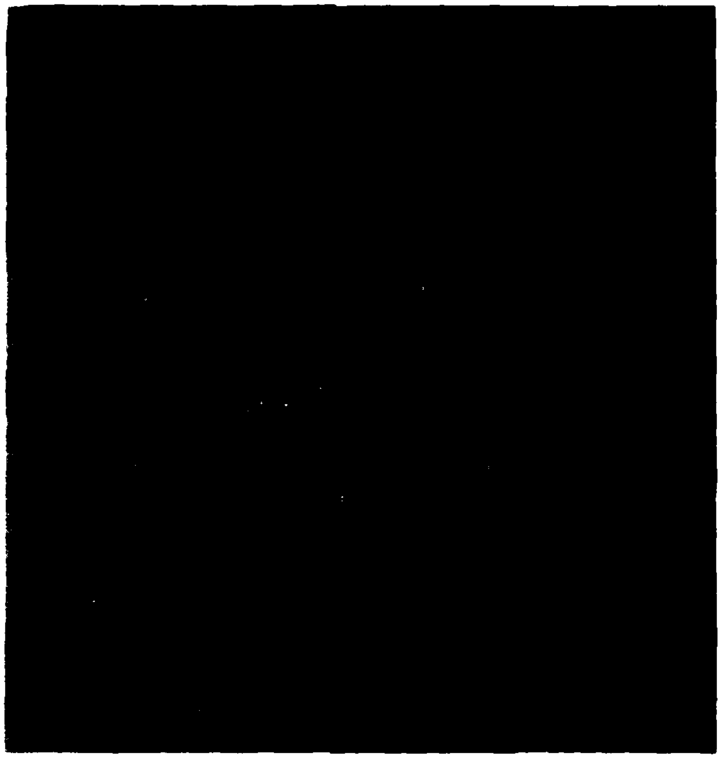

Figure 4. False Color Composite LANDSAT Image, Meyer Region, August Scene.

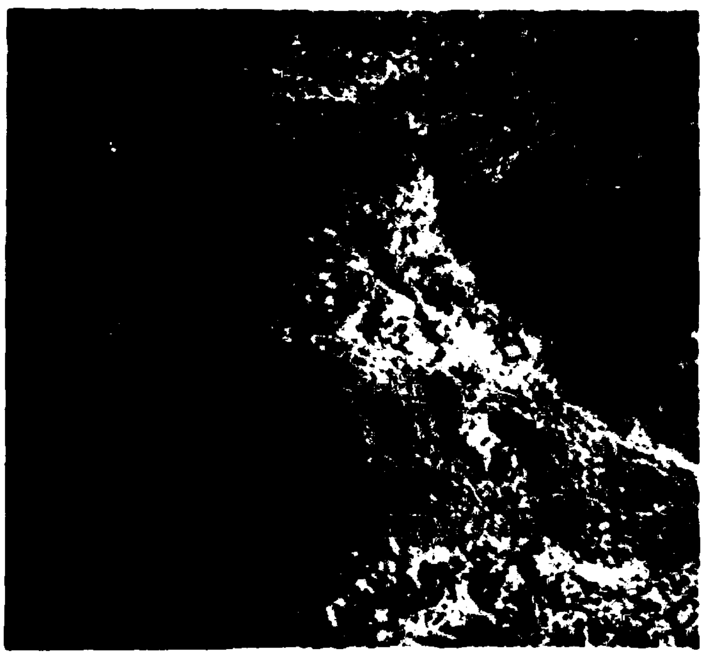

Figure 5. Color-Enhanced Classified LANDSAT Image, Meyer Region, August Scene. Numbered polygons correspond to those in Figure 4.

c. **Mountainous Areas.** These areas were characterized by two land cover classes; *Bouteloua curtipendula-Parthenium incanum* (16) and bare rock (90). Spectral class 16 occurred on the dissected limestone hills of the Hueco Mountains. Spectral class 90 represented the bare rock of the igneous and limestone mountains. The rock outcrops were frequently confused with spectral classes 16, 20, and 21 that had low vegetative cover and occurred on the upper alluvial fans. This confusion can be partially attributed to the spectral similarity between the coarse-textured limestone particles and limestone bedrock. The vegetative cover was not dense enough to modify the signatures of the alluvial surfaces. Where vegetation did occur, such as class 16, these land cover classes were recognized and classified (figures D11, D13, and D14).

2. **Dona Ana Region.** The Dona Ana region is located in the northwest portion of the study area. The area was approximately 414 pixels in the horizontal and 508 lines in the vertical dimension.

The land cover is primarily shrub communities dominated by *Larrea tridentata* and *Prosopis glandulosa* with some grass and grass-shrub communities. The forest community *Juniperus monosperma-Quercus undulata* (70) and bare rock (90) occur at the highest elevations.

The labeled polygons defining the 19 training fields of the Dona Ana region for the March and the August scenes are shown in figures 6 and 8, respectively. Seven spectral classes represented the 11 land cover units in this region. The signatures of the digital classes are presented in appendix C. The major land cover units selected for evaluation were *Scleropogon brevifolius-Hilaria mutica* (10C), *Larrea tridentata* (20), *Larrea tridentata*-grassland (21), *Larrea tridentata-Prosopis glandulosa* (23), *Prosopis glandulosa-Atriplex canescens-Xanthocephalum Sarothrae* (50), *Juniperus monosperma-Quercus undulata* (70), and bare rock (90).

The color-enhanced classified image for the March scene is shown in figure 7, and the classes and associated training field classification are summarized in table 3. The land cover classification was accurate to a level 3 classification. More detailed classification was not possible because of the similarity between the spectral signatures of some land cover units.

**Table 3. Summary of spectral classes and maximum likelihood classification of the training fields for the Dona Ana Region, March scene**

| SPECTRAL CLASS | COLOR | TRAINING FIELDS* |
|---|---|---|
| 10C | Red | (10C-11), 10C-10 |
| 20 | Lt Blue | (20-7), 10C-5, 20-6, 70-1, 21-7, 21-8, 90-5LH, 20-10, 21-11 |
| 21C | Buff | (21-10), (21-8), 20-6, 21-7, 50-10, 10C-10 |
| 23 | Orange | (23-5), 23-6, 90-5RH |
| 50 | Brown | (50-5), (50-6), 23-6, (50-10) |
| 70 | Green | 70-1, 10C-5, 20-6, 21-7, 21-8, 23-6, 90-5RH, 10C-10 |
| 90 | Purple | (90-5LH), 10C-5, 21-7, 23-6, 70-1, 90-5RH, 20-10, 21-11 |

*Training fields listed have ≥ 10% of the field's pixels classified to the spectral class shown. Fields enclosed in ( ) have ≥ 70% and those enclosed by (_) have ≥ 90% of the pixels classified to the class shown.

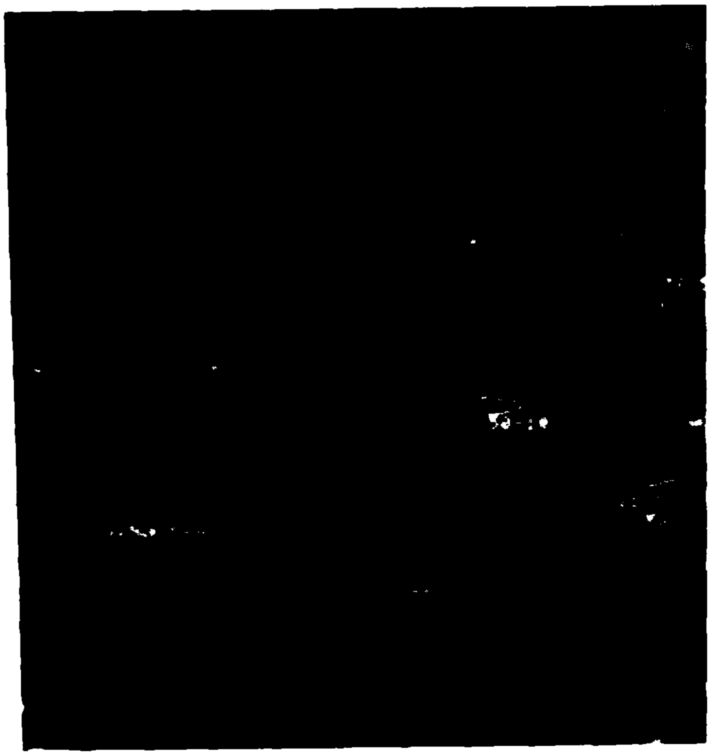

Figure 6. False Color Composite LANDSAT Image, Dona Ana Region, March Scene.

Figure 7. Color-Enhanced Classified LANDSAT Image, Dona Ana Region, March Scene. Numbered polygons correspond to those in Figure 6.

The Larrea tridentata communities (20 and 21) on the alluvial fans, the Prosopis glandulosa-Xanthocephalum Sarothrae-Atriplex canescens community (50) in the basin and the grasslands (10C), and the L. tridentata-P. glandulosa community (23) on the lower alluvial fans were appropriately classified for the most part. However, some dissimilar land covers were classified to the same spectral class. The following land cover units had similar signatures in some areas:

9 1. The Larrea tridentata communities (20, 21) on the upper alluvial fans and the Sporobolus flexuosus (10D) and grass-P. glandulosa (15) land cover units in the dark-toned depressions in the basin.

2. The Juniperus-Quercus community (70) in the mountain areas and L. tridentata-grass and L. tridentata-P. glandulosa communities on the lower alluvial fans and some depressions in the basin, i.e. the green-colored areas near polygons 6 and 10 in figure 7.

The color-enhanced classified land cover map for the August scene is shown in figure 9. The classes and associated training fields are summarized in table 4. The spectral classes generally conformed with the land cover classes of the ground truth data base. The land cover was generally classified to level 3. A higher level of classification was not possible because the land cover conditions were often confused in the maximum likelihood classification. The Larrea tridentata community (20) on the alluvial fans, the L. tridentata-Prosopis glandulosa community (23) on the lower alluvial fans, and the Prosopis glandulosa-Xanthocephalum Sarothrae-Atriplex canescens-grass community (50) in the basin were correctly mapped. The following land cover units had similar signatures in some areas:

1. Scleropogon brevifolius-Hilaria mutica grass (10C) on the fine-textured soils of the lower alluvial fans and some playas were confused with the limestone bedrock (90).

2. The Juniperus monosperma-Quercus undulata community (70) was confused with some grass-shrub and shub-grass communities in the playas and channel-like depression of the basin.

3. The L. tridentata (20) land cover unit on the upper alluvial fans and some grass-shrub communities in the linear depression in the basin.

4. The bedrock (90) and sparsely vegetated upper alluvial fans and some L. tridentata communities (20) on the upper alluvial fans.

Table 4. **Summary of spectral classes and maximum likelihood classification of the training fields for the Dona Ana Region, August scene**

| SPECTRAL CLASS | COLOR | TRAINING FIELDS* |
|---|---|---|
| 10C | Red | (10C-4), 10C-5, 10C-10 |
| 20 | Lt Blue | (20-7), 21-8, 10C-5, 20-6, 21-7, 20-10, 10C-10 |
| 21 | Buff | (21-10), (21-8), 20-6, 20-10, 23-6, 50-10, 10C-10 |
| 23 | Orange | (23-5), (23-6), 50-10, 10C-10 |
| 50 | Brown | (50-5), (50-6), 50-10 |
| 70 | Green | (70-1), 10C-5, 21-7 |
| 90 | Purple | (90-5LH), (90-5RH), 20-6, (20-10), (20-11), 10C-10 |

*Training fields listed have ≥ 10% of the field's pixels classified to the spectral class shown. Fields enclosed in ( ) have ≥ 70% and those enclosed by (_) have ≥ 90% of the pixels classified to the class shown.

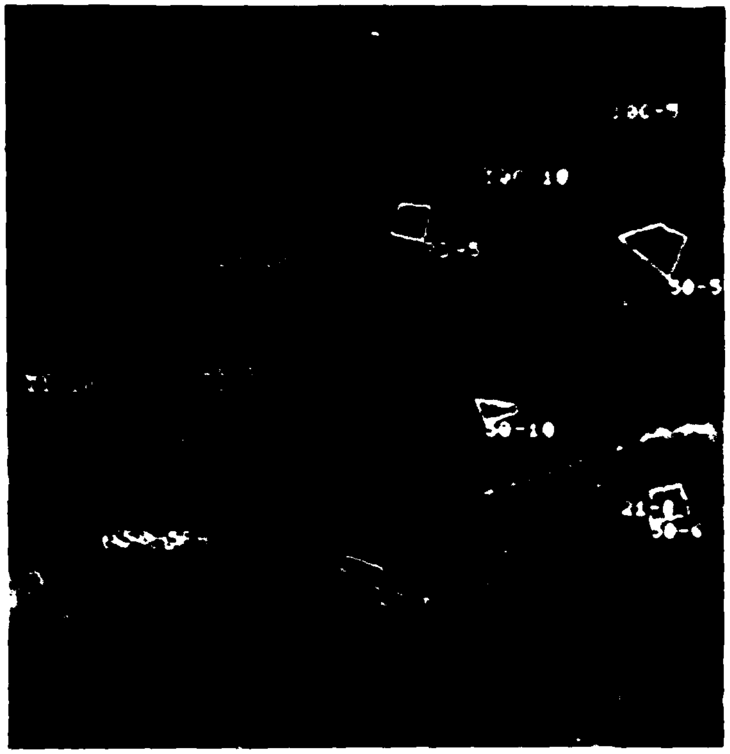

Figure 8. False Color Composite LANDSAT Image, Dona Ana Region, August Scene.

Figure 9. Color-Enhanced Classified LANDSAT Image, Dona Ana Region, August Scene. Numbered polygons correspond to those in Figure 8.

The similar signatures of these land cover conditions were caused by either the rock fragments on these soil surfaces or the dense grass understory. The upper fans were covered with gravel particles derived from the adjacent mountains. Therefore, the possibility of similar spectral signatures was high. Similarity was also found between limestone bedrock (polygon 11) and Old Coe Lake playa where the soil textures were clay, clayey silt, and silty clay with no surficial gravel. This confusion probably resulted from the presence of a dormant vegetation and other plant debris that were spectrally similar to the limestone bedrock.

**B. Seasonal Image Data.** The phenological effects of vegetation on the classified LANDSAT images were evaluated by comparing the class mean signature and the spatial distribution of the spectral classes on the March and August scenes. Because the training fields creating the spectral classes for the two regions were positioned in the same land cover units and in approximately the same geographical area on the two scenes, any differences in the class signatures indicate temporal changes in the vegetative cover and plant growth characteristics. A visual comparison of the color-enhanced and false color composite scenes was used as the basis for noting the differences between the two classified scenes.

**1. Meyer Region.** For the land cover units dominated by warm season grasses and shrubs, the class signatures had lower brightness levels in all LANDSAT bands for the March scene than for the August scene. However, there was an inconsistancy in the expected brightness level in relation to the plant growth and green vegetative cover in the land cover units. Brightness levels in bands 4 and 5 should vary inversely with cover, and brightness levels in bands 6 and 7 should vary directly with cover. The brighter pixel intensities (high values) in bands 4 and 5 indicated a lesser cover in these warm-season communities for the March image, which coincides with the species dormancy period. These same communities had high brightness in bands 6 and 7, which indicated an increased cover. The signatures for the communities dominated by cool-season grasses (10C) and shrubs (60) had high brightness values in bands 4 and 5, which indicated a lesser cover in the March scene. The lower brightness levels in bands 6 and 7 indicated a lower cover (table 5). The bare rock class (90) had brighter signatures in all bands for the March scene compared to those of the August scene.

**Table 5. Ratio of the class mean signature in the four LANDSAT bands for the March image to those of the August image, Meyer Region**

| CLASS | SPECTRAL BANDS | | | | VEGETATION INDEX* | |
|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | March | August |
| 10C | 1.14 | 1.32 | 1.04 | 1.00 | -0.28 | -0.14 |
| 10D | .91 | .97 | .90 | .95 | -0.34 | -0.34 |
| 16 | .95 | 1.01 | .91 | .95 | -0.33 | -0.30 |
| 20 | .90 | .94 | .97 | 1.05 | -0.34 | -0.39 |
| 21 | .95 | .97 | .95 | 1.02 | -0.31 | -0.33 |
| 50 | .93 | .95 | .92 | .97 | -0.35 | -0.36 |
| 60 | 1.01 | 1.25 | 1.10 | 1.14 | -0.35 | -0.30 |
| 90 | 1.04 | 1.08 | 1.06 | 1.12 | -0.36 | -0.38 |

**Note:** A ratio less than 1.00 means the March signature was darker (small value) than the August signature. A value greater than 1.00 means the March signature was lighter (large value) than the August signature (calculated from data in appendix C).

*Vegetation Index = (MSS7 - MSS5)/(MSS7 + MSS5)

Comparing the classified March and August scenes for the Meyer region shows that the vegetation index (VI), which was calculated for the land cover classes, varied over a very small range; -0.27 to -0.36 for the March scene and 0.14 to 0.39 for the August scene. The difference between these ratios was quite small, which prevented using the ratio technique for discriminating the land cover units.

The negative index values are the result of the manner in which the class mean brightness values are processed. A zero pixel value represents the brightest pixel level and a value of 255 represents the darkest pixel value. Arithmetic processing of the MSS5 and MSS7 values in computing the vegetation index value does not consider the reversed association of the pixel brightness value and pixel numerical value. The pixel density histograms show the MSS4 and MSS5 data are slightly darker than the MSS7

data while the MSS6 data are the darkest of the 4 LANDSAT bands. A reason for the small contrasts and the dark values associated with MSS6 data is the pre-processing of the LANDSAT digital data. [10]

Some obvious differences were found in the spatial distribution of the land cover unit on the two scenes (figures 3 and 5). Differences of land cover classification are summarized by major landform conditions.

Basin:
1. Increase of the Artemisia filifolia-Sporobolus flexuosus community (60)
2. Increase of the Larrea tridentata (20)
3. Decrease of Sporobolus flexuosus community (10C)
4. Decrease of Prosopis glandulosa community (50)

Alluvial fans:
1. Increase of Scleropogon brevifolius-Hilaria mutica grassland (10D)
2. Increase of bare rock soil (90)
3. Increase of Bouteloua curtipendula-Parthenium incanum (16)
4. Increase of Larrea tridentata-grass (21) in some areas and decreases in other areas
5. Increase in Sporobolus flexuosus-S. cryptandrus (10C)
6. Decrease in L. tridentata (20)

Mountains/Hills:
1. Increase of bare rock (90)
2. Decrease of Bouteloua curtipendula-Parthenium incanum (16) at polygon 12 but increase at polygon 11

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[10]U.S. Geological Survey, 1979. Landsat Data Users Handbook, Revised Editions. U.S. Department of Interior. Arlington VA 22202

2. **Dona Ana Region.** The mean class signature ratios show that warm season land cover units 20, 23, 50, and 90 had darker class signatures in the March scene than in the August scene (table 6). These land covers were mostly warm season species that achieve maximum growth and vegetative cover during August and September. Because the warm season species in the March scene were in a reduced leaf stage, or devoid of leaves, a greater percentage of the soil surface contributed to the class signature.

**Table 6. Ratio of the class mean signature in the four LANDSAT bands for the March image with those of the August image and Vegetation Index, Dona Ana Region**

| CLASS | LANDSAT BAND | | | | VEGETATION INDEX* | |
|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | March | August |
| 10C | 0.89 | 0.80 | 1.30 | 1.60 | -0.09 | -0.40 |
| 20 | 0.92 | 0.92 | 0.90 | 0.95 | -0.34 | -0.35 |
| 21 | 0.83 | 0.80 | 0.93 | 1.03 | -0.27 | -0.39 |
| 23 | 0.94 | 0.99 | 0.92 | 0.97 | -0.36 | -0.35 |
| 50 | 0.91 | 0.95 | 0.91 | 0.97 | -0.36 | -0.36 |
| 70 | 1.05 | 1.17 | 0.97 | 0.98 | -0.32 | -0.23 |
| 90 | 0.81 | 0.81 | 0.87 | 0.97 | -0.33 | -0.41 |

**Note:** A ratio less than 1.00 means the March signature was darker (small value) than the August signature. A value greater than 1.00 means the March signature was lighter (large value) than the August signature (calculated from data in appendix D).

*Vegetation Index (VI) = (MSS7 - MSS5)/(MSS7 + MSS5)

Land covers of cool season grasses, shrubs, and trees (10C and 70) had lower reflectance in bands 4 and 5, and higher reflectance in bands 6 and 7 of the March scene compared with the same bands of the August scene. The low reflectance in the visible region and high reflectance in the infrared region indicates a green vegetation.[11] This condition was seen in the spectral classes 10C and 21 in which the cool-season vegetation increased in March, but decreased in August when this vegetation was dormant. The MSS5 and MSS7 ratio data, for the March scene ranged from -0.09 to -0.36, and from -0.23 to -0.41 in the August scene. The ratios for most classes were too narrow for using the ratio technique to discriminate among the land cover units.

Major land cover units in the Dona Ana region had the same general distribution on both classified images (figures 7 and 9). The differences between the scenes are summarized as follows:

Basin:

1. Reduction of the *Larrea tridentata-Prosopis glandulosa* community (23)
2. Increase in *L. tridentata*-grass (21)
3. Increase of the *Juniperus monosperma-Quercus undulata* (70)
4. Reduction in the *Larrea tridentata-Prosopis glandulosa* (23) and *Larrea tridentata*-grass (21) in the transition from the basin to the alluvial fans near polygon 10
5. Increase in the *Scleropogon brevifolius-Hilaria mutica* grassland (10C)

Alluvial Fans:

1. Increase in bare rock (90) and decrease in *L. tridentata* (20) and *L. tridentata*-grass (21) on the alluvial fans of the Organ Mountains (polygon 14)
2. Increase in *L. tridentata* (20) and decrease in *L. tridentata*-grass (21) on fans around Organ Mountains
3. Increase in Larrea tridentata (20) but decrease in bare rock (90) on the alluvial fans of the Franklin Mountains

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[11]Melvin B. Satterwhite, Ponder Henley, and Miklos Treiber, 1982. *Vegetative Cover Effects on Soil Spectral Reflectance*, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, ETL-0284.

Mountains/Hills:

1. Decrease in Juniperus monosperma-Quercus undulata (70) and increase in L. tridentata (20) in the Organ Mountains (polygons 3 and 4)

2. Decrease in bare rock (90) in Franklin Mountains and increase in L. tridentata (20)

3. Decrease in Scleropogon brevifolius-Hilaria mutica (10C) on Franklin Mountains (a ·is-classification of land cover) and increase in L. tridentata (20)

## DISCUSSION

The level 3 land cover classification achieved from these LANDSAT scenes was possible because of prior knowledge of the relations between the land cover and the landform conditions. Because the larger land cover units on the alluvial fans, basins, and mountain areas had spectral reflectance characteristics sufficiently different, they could be digitally separated and mapped on the LANDSAT image. For other land cover units, the spectral reflectance characteristics were so similar to those of the larger units that they could not be separated into different classes.

The confusion observed on the classified image could be resolved by evaluating the landform-land cover associations and by using the species phenological characteristics. The confusion between land covers on the general landform conditions could not be graphically removed from the classified map because there is presently no mechanism for incorporating the landform data into the image classification process.

General landform conditions were recognized on the color composite LANDSAT image and were used in the image analysis process. The soil texture and soil depth conditions commonly associated with these landform units, i.e. coarse-textured shallow soils on upper alluvial fans and mountainous areas and fine-textured deep soil on the lower fans, playas, and basins, showed the out-of-place land cover class on a landform unit, which demonstrated the need for additional class evaluation. The spectral signatures of some playas and the mountainous areas in the Meyer and Dona Ana regions were similar, which led to the classification of some playas as rock outcrops that were associated with mountainous areas. Left unresolved, the class map showing this information could lead to management practices that were reasonable for one condition but not for the other. Instances such as these necessitate the use of landform data in the image evaluation and analysis process.

Any LANDSAT digital classification is based on a comparison of the spectral reflectance characteristics from different instantaneous fields of view. The spectral reflectance signature recorded in the four LANDSAT bands depends on the reflectance properties of the vegetation and soil types, the ratio of vegetation to soil, the physiological condition of the plants (live, dead, young, old), and the moisture condition of the soil surface. This signal is also influenced by the fairly broad bandpass of each LANDSAT band. Thus, two objects can have different spectral reflection characteristics over the wavelengths assigned to any given band, and yet can have the same average intensity value. In such a case, the two objects would be combined into the same spectral class. In these scenes, the contrast, or brightness, range was so small in all the bands that it was not possible to assign significantly different brightness levels to specific land cover units. The spread was but 30 units in bands 4 and 7, and 75 units in bands 5 and 6.

Visually comparing the ground truth maps and the digital classified maps shows that the spatial distributions of the land cover units varied between the two data sets. The noted differences occurred on the same major landform condition — basin, alluvial fans and washes, or mountains and dissected hills. This involved variations in the species composition, percent vegetative cover, and soil conditions on these landform units.

The phytosociological differences found in the ground truth data were not associated with distinct class signatures of some land covers. For example, land cover units Sporobolus flexuosus-Artemisia filifolia (14) and Artemisia filifolia-S. flexuosus (60) had the same species compositions, but varied by the dominants or subdominants in the community. These land cover units had the same spectral signature. The need for a distinct signature for each land cover category is a reason that the level of land cover classification based on field data could not be duplicated using the MSS digital data. The discrete class signature was not associated with the dominant plant species of the land cover unit. The similar spectral signatures for some grass-shrub and shrub-grass communities apparently resulted from the dense grass cover. This was found in the grass-shrub and shrub-grass communities where the dominant shrub species lacked sufficient cover or reflectance contrast with the understory and soil background to provide a discriminating signature. In instances as these, the dense grass cover provided the major portion of the class signature (i.e. communities 14, 15, 60, and 61). Similarly, different communities with low vegetative cover on the same soil conditions were often confused because the soil's signature was not attenuated by the vegetative cover. This was found in the basin where some P. glandulosa communities (50) were confused with the sparsely vegetative S. flexuosus (10D) and A. filifolia (60) communities.

Different land cover units on dissimilar landform conditions could have similar spectral signatures caused by shadows, by dense dormant plant material, by debris, or by surface material, all of which can cause confusion in their land cover classification. The shadows of the mountain areas of the Dona Ana region were similar to the dense dormant vegetative cover in the playas and in the depressions of the basin in both the March and August scenes. This dormant vegetative cover on the lower fans and in the basin depressions was also spectrally similar. Consequently, the effects of shadow and plant debris are important factors that cause confusion between land cover units, particularly the land cover units in mountainous terrain and those with dense vegetative cover such as in the washes, lower alluvial fans, and the depressions and playas in the basin.

Most soils in the Meyer and Dona Ana regions were highly reflective. Thus, when a large percentage of bare soil occurred in a land cover unit, the soil's reflectance characteristics dominated the class spectral signature. The reflectance from these soils is much greater than that of green vegetative cover, e.g. Prosopis glandulosa in the visible region, and is slightly less in the infrared region. For a gray-toned vegetation such as Artemisia filifolia, the reflectance contrast between the soil and vegetation in the visible range is still large, but it is less than for a green vegetation. In the infrared region, the soil and A. filifolia reflectance contrast is quite small.[12] Change in the vegetative cover that occurs naturally over the growth cycles can alter the reflectance contrast of the land surface and the land cover class signature.

The differences in the land cover classification between the two scenes were not the result of the drastic change in species composition that occurred between March and August. The differences resulted from change in the vegetative cover of these plant communities. Those communities with a dense, actively growing vegetative cover correspond with the red color on the color composite image. This was possible by assigning the three primary colors blue, green, and red to the MSS bands used for creating color composite images; MSS4-blue, MSS5-green, and MSS7-red. The reddish portions of the composite image indicated those areas with low visible reflectance, 500 to 700 nm, and high infrared reflectance, 800 to 1100 nm. Hence, the seasonal vegetative growth in the land cover units was depicted in the seasonal composite image. In the March color composite image, the land cover units with a dense, actively growing vegetative cover was shown by the reddish image tone. However, the same areas were not found in the August image. The differences indicate a growth-state change in the vegetation of these land cover units.

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[12] Melvin B. Satterwhite, Ponder Henley, and Miklos Treiber, 1982. Vegetative Cover Effects on Soil Spectral Reflectance, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA, ETL-0284.

Most shrub and shrub-grass communities were not apparent in either composite image. Even in the August scene, when the warm season shrub and grasses were fully leafed out and actively growing, the vegetative cover in these communities was not dense enough to be depicted on the color composite image. The data present in tables 5 and 6 also show the seasonal changes in the reflectance of the land cover units and the class signatures for the two scenes. Comparisons between the March and August scenes illustrate that the seasonal differences in plant growth can vary substantially over the growth cycle of cool and warm season species.

Ground level spectral measurements have shown that vegetation and soil targets have lower visible spectral reflectance than near infrared reflectance. In the four LANDSAT bandpasses soils have a greater spectral reflectance than the green vegetation in MSS bands 4 and 5 but the green vegetation has a greater spectral reflectance than the soil in the MSS bands 6 and 7. Based on these spectra, the pixel brightness values in MSS bands 4 and 5 should be less than the pixel brightness values in MSS bands 6 and 7. The scene pixel brightness values (Appendix A) and the class mean brightness values (Appendix B and C) show the mean pixel intensity levels in MSS bands 4 and 5 are slightly darker (higher values) than the pixels of MSS band 7 (low values), and the pixel values for MSS band 6 are the darkest values. The gain factors of these 4 bands used in the pre-processing of the LANDSAT band radiometeric data may be probable factors causing this inconsistancy between ground level spectra and LANDSAT pixel intensity levels. The relationship of the pixel brightness levels between the 4 bands is important for it directly affects assessment of seasonal plant growth and vegetative cover using the LANDSAT data. Evaluations of soil and vegetation differences between two different LANDSAT scenes in the same MSS band of the same area, can be a reasonable accomplishment, assuming the pre-processing functions are applied equally to both LANDSAT images. Pixel intensity differences between the two LANDSAT scenes could be associated with differences in vegetative cover and plant growth. This relation between vegetative cover and band brightness level that was developed from ground level studies could be generally applied with consideration given to the differences in atmospheric conditions and solar illumination. Comparisons using the LANDSAT spectral data of two band-passes must consider the effect of the pre-processing activity on the sensor's radiometric data in each band. The pre-processing apparently reduces the reflectance contrast between the bands for some soil or vegetation conditions and changed the relation of the visible and band 6 near infrared spectra. The vegetation index (VI) is a ratio relating vegetation cover and bare soils by their reflectance spectra in bands 5 and 7. Ground level measurements have shown VI values approaching 1.0 are indicative of green vegetation because of the high contrast between vegetation reflectance in bands 5 and 7, and VI values approaching 0.1 are indicative of soils because of the small reflectance contrast between bands 5 and 7. The VI ratios computed from the class signatures in this

study have a narrow range of values, for which no association was found between the sparse or dense vegetative cover. This could have been a consequence of the pre-processing of the radiometric data that reduced the contrast between MSS 5 and MSS 7 data for the vegetation and soil conditions.

Understanding the species annual growth cycles, knowing the relations of cover and soil reflectance, and understanding species-landform relations, soil-landform relations, and anticipated seasonal reflectance responses can help in interpreting classified digital images. The interpretation is an important matter that must rely on ground truth information and some other data for inferring plant-landform-soil relations. If properly used, this information can permit a level 3 or 4 digital classification.

The significance of the comparisons between seasonal classified images was the consistent mapping of the major land cover-landform conditions. The spectral classes for each scene are indicative of uniform or closely related conditions. However, there was some confusion in the land cover classification of the same geographical area in the two scenes.

The factors affecting the class signature were the seasonal variations in percentages of vegetative cover, dormant biomass, and bare soil/rock in the land cover units. These changes resulted in some grass-shrub and shrub-grass land cover units being misclassified. The classification of some areas to one class in the March scene and to another in the August scene and the variations in class signature can be explained as seasonal vegetation growth characteristics.

## CONCLUSIONS

1. Land cover classification from analysis of LANDSAT data was carried to a level 3 in most cases and to level 4 in some cases. The Anderson land use/land cover classification system was used as the classifying basis. The classification levels and results could not have been obtained without an adequate ground truth data base.

2. Supervised classification of land cover conditions generally conformed to the landform conditions. Misclassification of the plant communities was mostly between those present on the same major landform unit. Resolving some misclassified land cover units was possible by using the land cover-landform associations determined from ground truth data.

3. Some grass and grass-shrub land cover units were classified to the same class beca se of the effects of the dense grass cover. The grass cover could be either the dominant or the subdominant component in the land cover units, but its spectral characteristics dominated the land cover signatures, causing misclassification of some land cover units.

4. The uniform signature of the surficial materials caused misclassification of some land cover units with sparse vegetative cover. The surficial gravel particles were the probable factor for the spectral similarity between some upper alluvial fans and the adjacent areas with exposed bedrock.

5. Other factors, such as shadow areas in the mountain/hill landform unit, were confused with the dark-toned land cover units in the playas.

6. Species phenological characteristics affected the class spectral characteristics in the four bands in both LANDSAT scenes. Evaluation of the spectral differences in view of species phenological differences facilitated interpreting the land cover classification.

7. Phenological changes were most conspicuous in grass, grass-shrub, and shrub-grass land cover units.

## APPENDIX A.

### Histograms of the Pixel Density Distribution for the Four LANDSAT Bands, March and August Scenes

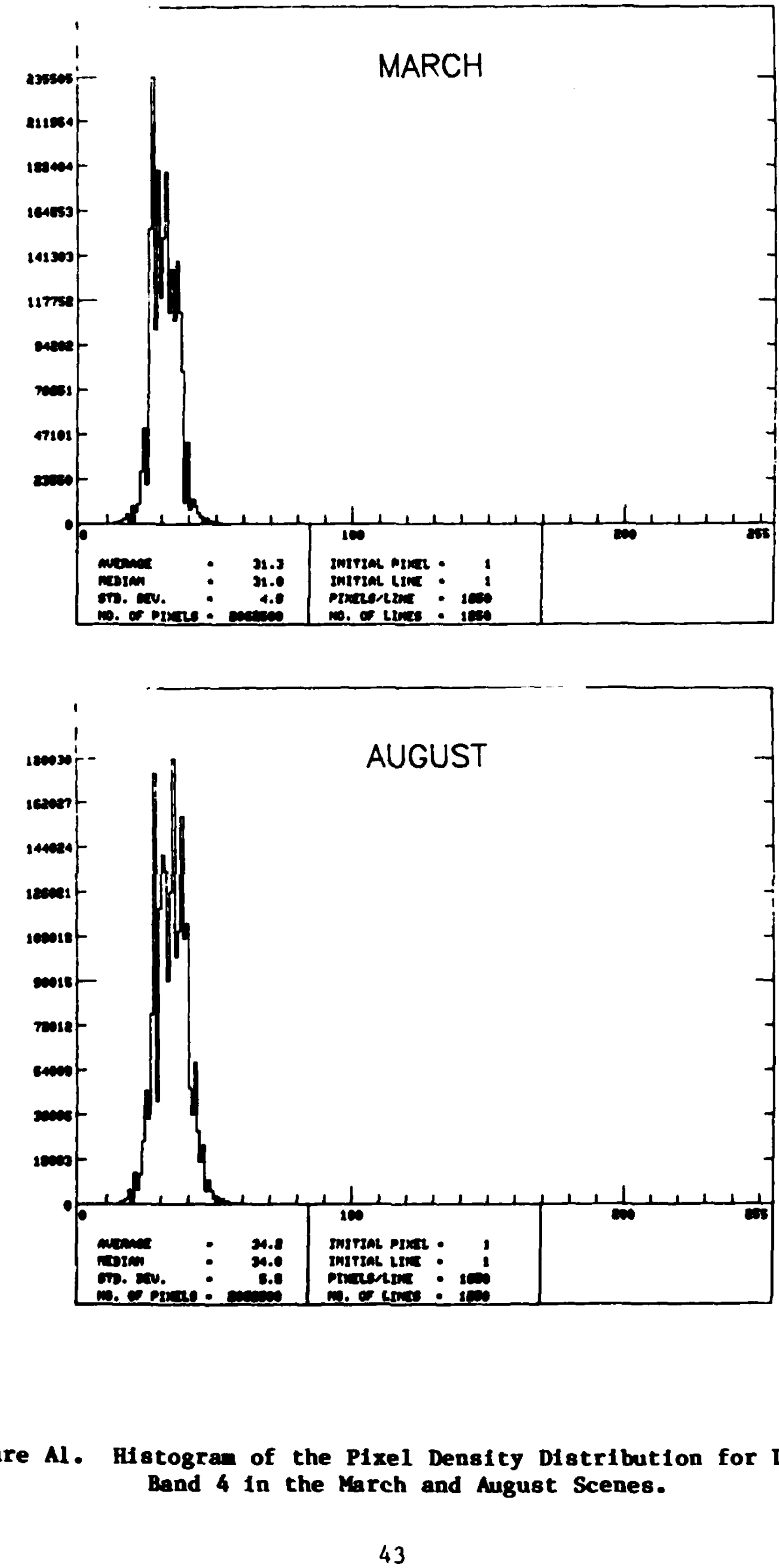
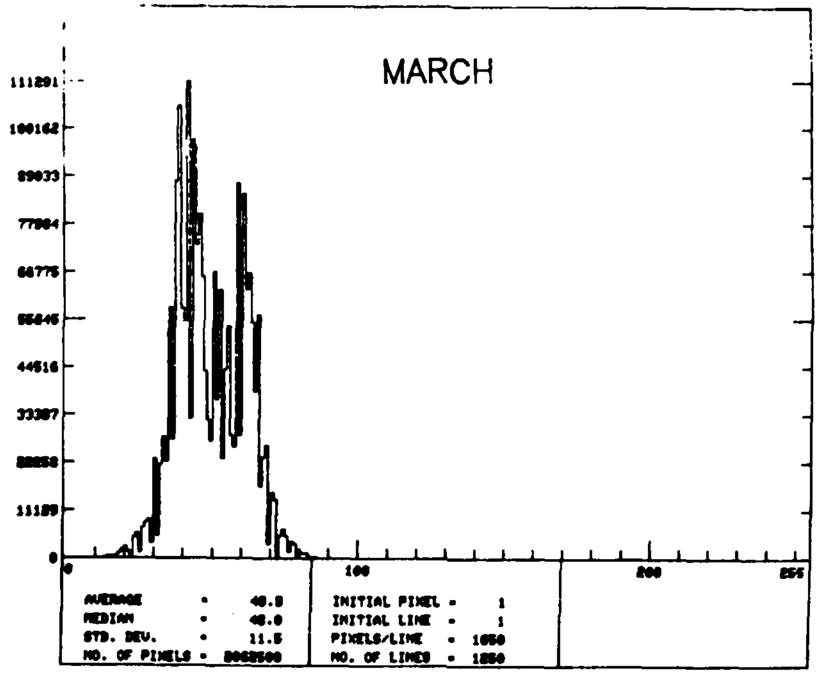



**Figure A1. Histogram of the Pixel Density Distribution for LANDSAT Band 4 in the March and August Scenes.**



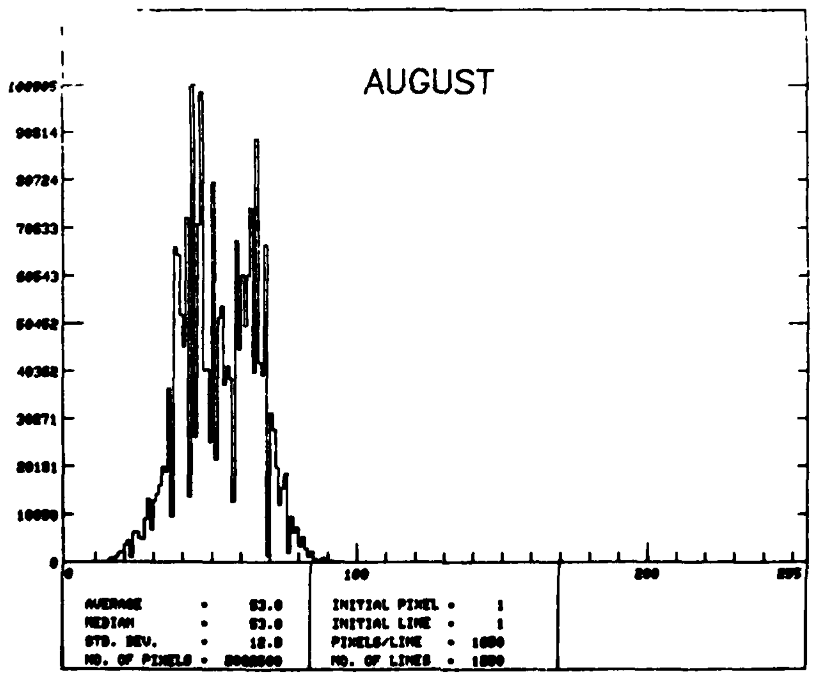




**Figure A2. Histogram of the Pixel Density Distribution for LANDSAT Band 5 in the March and August Scenes.**

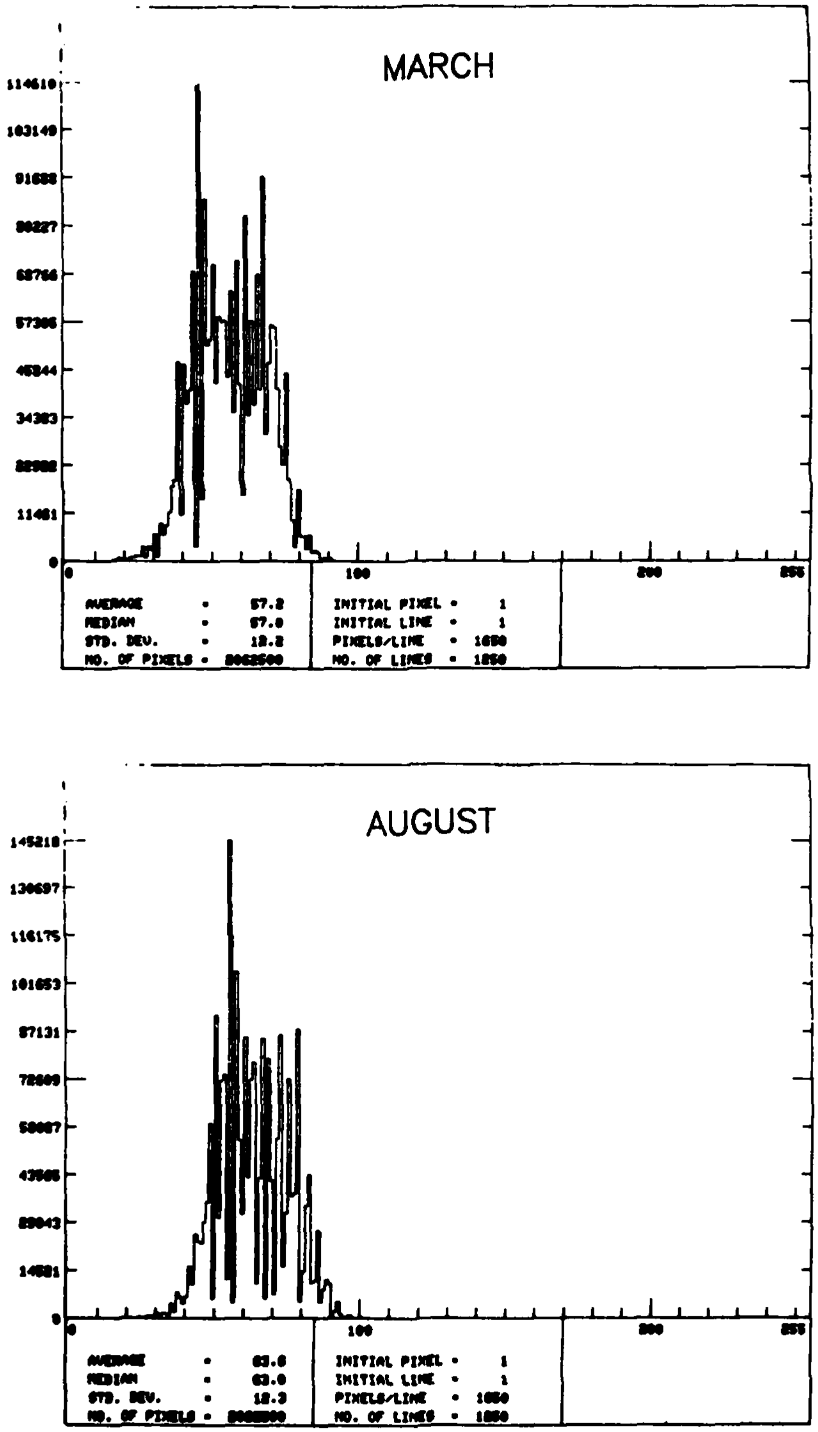



**Figure A3. Histogram of the Pixel Density Distribution for LANDSAT Band 6 in the March and August Scenes.**

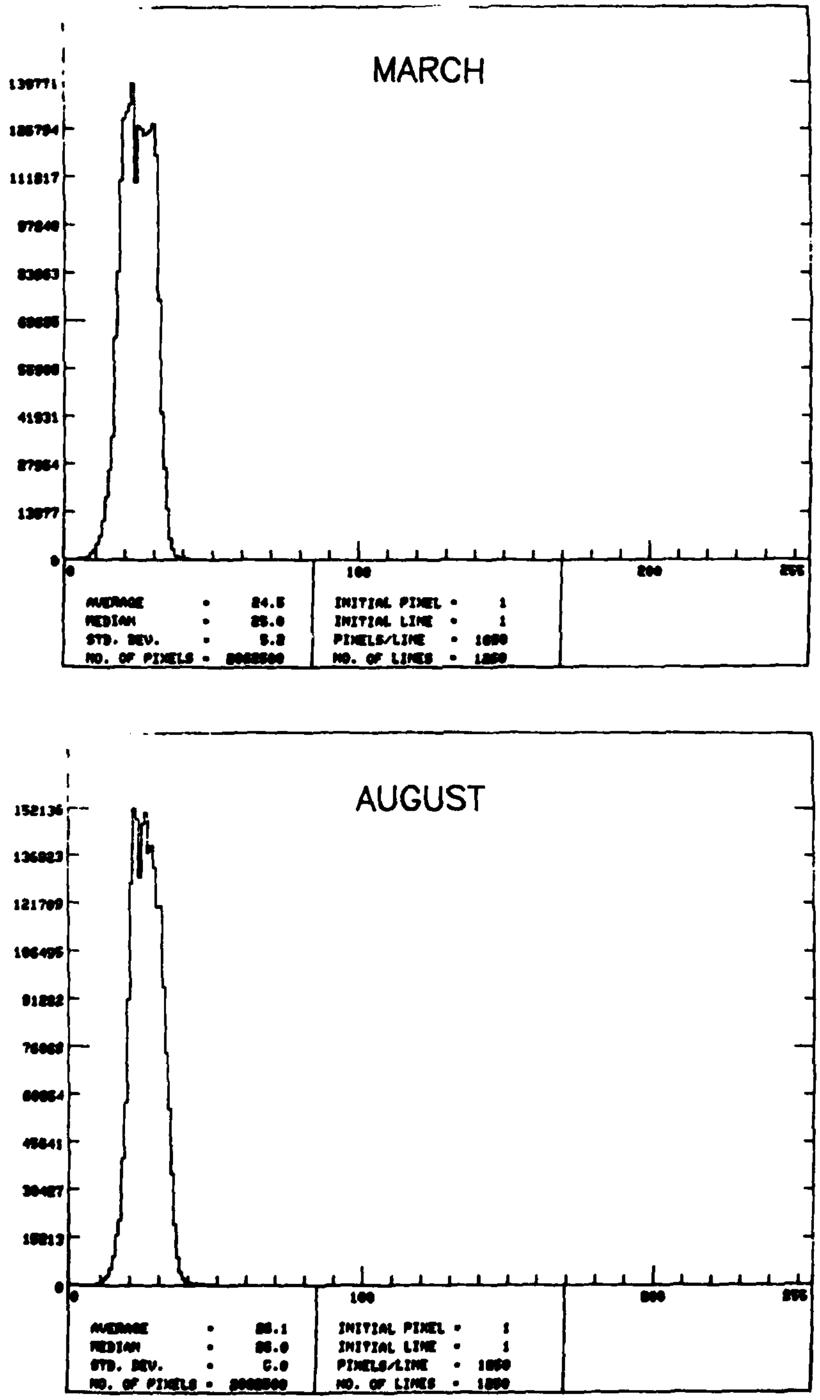



Figure A4. Histogram of the Pixel Density Distribution for LANDSAT Band 7 in the March and August Scenes.

## APPENDIX B.

**Signatures for Classes in the Meyer Region, March and August Scenes**

| Band | CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10C | | 10D | | 16 | | 20 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 31.94 | 4.79 | 27.76 | 1.12 | 27.48 | 1.51 | 33.04 | 2.23 |
| 5 | 46.89 | 8.72 | 48.09 | 3.20 | 38.71 | 3.05 | 52.78 | 3.99 |
| 6 | 59.55 | 6.90 | 54.85 | 3.42 | 44.64 | 3.40 | 60.06 | 3.86 |
| 7 | 26.57 | 2.64 | 23.39 | 1.45 | 19.63 | 1.49 | 25.77 | 1.66 |

| Band | CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 21 | | 50 | | 60 | | 90 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 30.67 | 1.85 | 33.67 | 2.19 | 29.79 | 1.28 | 27.51 | 5.43 |
| 5 | 44.10 | 2.68 | 64.52 | 3.71 | 56.86 | 2.39 | 38.10 | 10.01 |
| 6 | 52.94 | 2.81 | 72.63 | 4.61 | 65.18 | 2.70 | 43.27 | 11.21 |
| 7 | 23.14 | 1.09 | 31.04 | 1.92 | 27.74 | 1.13 | 17.84 | 4.98 |

**Figure B1. Class Signatures for the Meyer Region, March Scene.**

| Band | CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10C | | 10D | | 16 | | 20 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 28.09 | 3.21 | 30.38 | 1.09 | 29.00 | 2.78 | 36.64 | 1.77 |
| 5 | 35.50 | 6.62 | 49.78 | 2.18 | 38.15 | 5.08 | 55.99 | 3.09 |
| 6 | 57.18 | 3.71 | 60.68 | 2.56 | 48.97 | 5.46 | 61.94 | 3.25 |
| 7 | 26.64 | 1.43 | 24.65 | 1.13 | 20.66 | 2.37 | 24.63 | 1.47 |

| Band | CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 21 | | 50 | | 60 | | 90 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 32.27 | 1.31 | 36.22 | 1.80 | 29.58 | 1.35 | 26.46 | 4.28 |
| 5 | 45.53 | 2.09 | 68.21 | 2.60 | 45.67 | 2.67 | 35.40 | 7.02 |
| 6 | 55.52 | 2.10 | 79.33 | 2.86 | 59.55 | 2.91 | 40.89 | 7.92 |
| 7 | 22.79 | 0.92 | 31.86 | 1.19 | 24.35 | 1.15 | 15.88 | 3.48 |

**Figure B2. Class Signatures for the Meyer Region, August Scene.**

## APPENDIX C.

**Signatures for Classes in the Dona Ana Region, March and August Scenes**

| Band | CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10C | | 20 | | 21 | | 23 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 24.18 | 1.31 | 27.13 | 0.90 | 26.65 | 0.84 | 35.25 | 1.42 |
| 5 | 31.05 | 2.69 | 39.95 | 1.52 | 40.79 | 1.84 | 54.53 | 2.65 |
| 6 | 53.41 | 3.74 | 46.99 | 2.05 | 52.79 | 2.16 | 60.44 | 2.24 |
| 7 | 26.23 | 1.82 | 19.90 | 0.93 | 23.37 | 0.93 | 25.72 | 0.82 |

| Band | CLASS | | | | | |
|---|---|---|---|---|---|---|
| | 50 | | 70 | | 90 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 34.19 | 1.58 | 25.78 | 5.18 | 28.31 | 2.87 |
| 5 | 60.10 | 2.51 | 36.56 | 8.82 | 39.35 | 5.03 |
| 6 | 66.87 | 2.65 | 44.06 | 10.56 | 46.08 | 5.99 |
| 7 | 28.50 | 1.09 | 19.22 | 5.04 | 19.92 | 2.83 |

Figure C1. Class Signature for the Dona Ana Region, March Scene.

| Band | CLASS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10C | | 20 | | 21 | | 23 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 27.18 | 1.32 | 29.33 | 1.23 | 32.16 | 1.59 | 37.41 | 1.58 |
| 5 | 38.68 | 2.19 | 43.45 | 1.78 | 50.94 | 3.15 | 55.17 | 2.75 |
| 6 | 41.17 | 2.72 | 52.35 | 2.30 | 56.98 | 2.76 | 65.64 | 2.29 |
| 7 | 16.44 | 1.21 | 20.92 | 1.01 | 22.58 | 1.01 | 26.52 | 0.90 |

| Band | CLASS | | | | | |
|---|---|---|---|---|---|---|
| | 50 | | 70 | | 90 | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 4 | 37.60 | 1.37 | 24.54 | 4.40 | 34.98 | 2.64 |
| 5 | 63.14 | 2.36 | 31.30 | 7.57 | 48.88 | 4.45 |
| 6 | 73.61 | 2.65 | 45.48 | 9.21 | 52.68 | 4.47 |
| 7 | 29.43 | 0.95 | 19.60 | 4.19 | 20.61 | 1.92 |

**Figure C2. Class Signature for the Dona Ana Region, August 1975.**

## APPENDIX D.

## Ground Level and Low Altitude Photography of Selected Land Cover Conditions

**Figure D1.** Sporobolus flexuosus-S. cryptandrus Community (10D) in the Basin Area (Site 174). Photograph was taken within the area of polygon 3 in figure 3 and polygon 21 in figure 5.

**Figure D2.** Sporobolus flexuosus-S. cryptandrus Community with Artemisia tridentata and Xanthocephalum Sarotharae Shrubs (Site 173). This photographs was taken within the area of polygon 11 in figure 5.

**Figure D3.** Ground view of Prosopis glandulosa-Atriplex canescens-Xanthocephalum Sarotharae Community (50) in the coppice dune area. This is typical of land cover in polygons 1 and 2 in figure 3 and polygons 12 and 13 in figure 5.

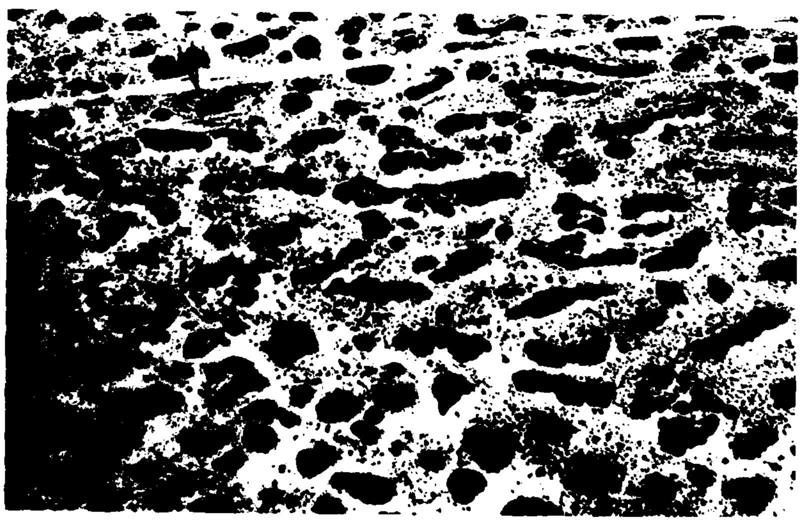


**Figure D4.** Low aerial oblique photograph of the Prosopis glandulosa-Atriplex canescens-Xanthocephalum Sarotharae community (50) in the coppice dune area. This is typical of the landcover in polygons 1 and 2 in figure 3 and polygons 12 and 13 in figure 5.

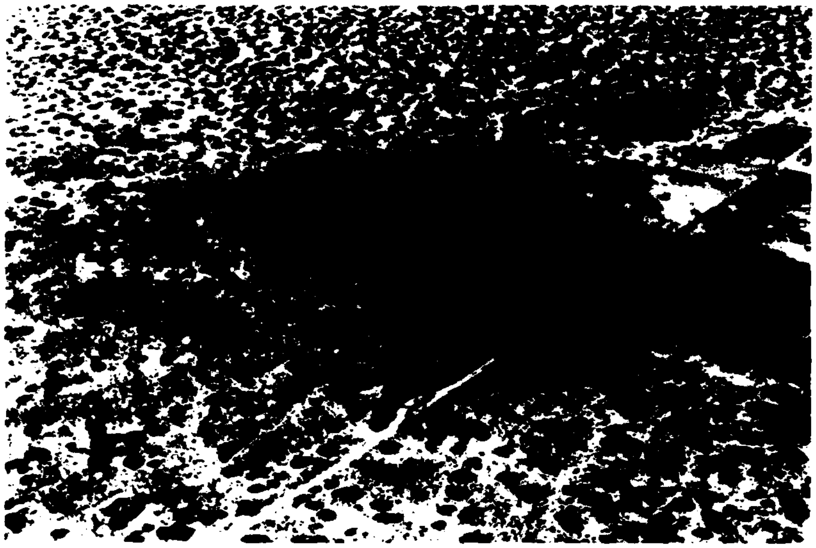


**Figure D5.** Dark-toned depressions and playa in the basin (C4) have a grass cover of Hilaria mutica, Muhlenbergia arenacea and annual species. The dark-toned patches outside the depression are coppice dunes with Prosopis glandulosa and Atriplex canescens shrubs. This land cover is typical of that in polygon 6 in figures 7 and 9.

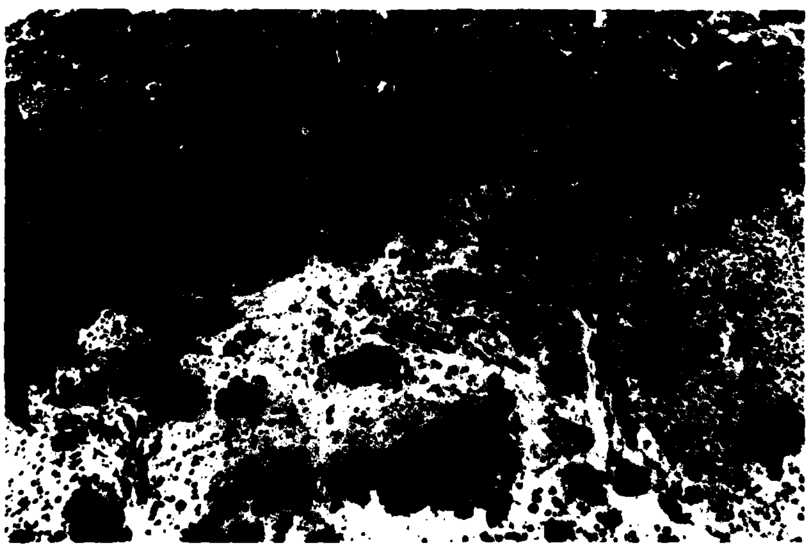


**Figure D6.** Transition from Prosopis glandulosa - Atriplex canescens community on coppice dunes to the Prosopis glandulosa - A. canescens community with a dense understory of Hilaria mutica and Scleropogon brevifolius.

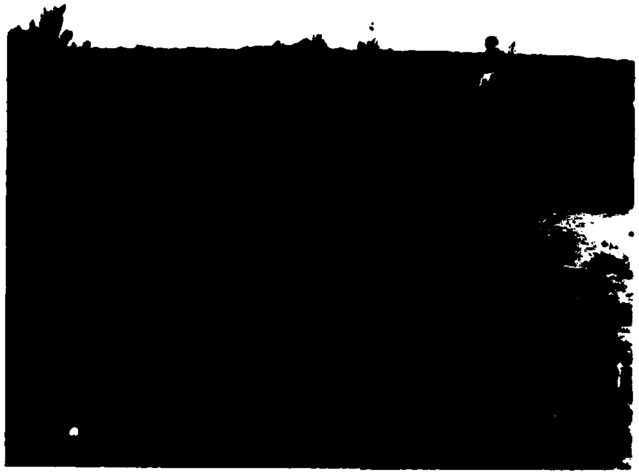


**Figure D7.** Artemisia filifolia-grass community (60) on dark-toned, rough-textured dunes. This land cover is typical of that in polygon 6 in figure 3.

**Figure D8.** Flourensia cernua-grass community (41) on wash area (d). The grass cover is Hilaria mutica and Scleropogon brevifolius.

**Figure D9.** Scleropogon brevifolius-Hilaria mutica community (10D) on the lower alluvial fan. This land cover is typical of that represented by polygon 10 in figures 3 and 5.

**Figure D10.** Larrea tridentata-grass community (21) on the lower alluvial fan. The grass species is Muhlenbergia Porteri, (site 41). This land cover is typical of the community represented by polygons 9 and 18, figure 3; and polygon 1, in figures 7 and 9.

**Figure D11.** Larrea tridentata community on the upper alluvial fan of the western slope of the Franklin Mountains (Site 70). Note the bare gravel-covered soil surface beneath the shrub overstory. This photo is of the area in polygon 17, figures 7 and 9.

**Figure D12.** Upper reach of a wash with Larrea tridentata-Flourensia cernua community in the foreground, L. tridentata in the middle of the photograph, and Bouteloua curtipendula-Parthenium incanum (16) on the hills. This is typical of the land cover/landform relations in areas near polygons 9, 12, and 15 in figure 3.

**Figure D13.** Acacia constricta-Larrea tridentata community on upper alluvial fans (site 2/3) in polygon 17, figure 5.

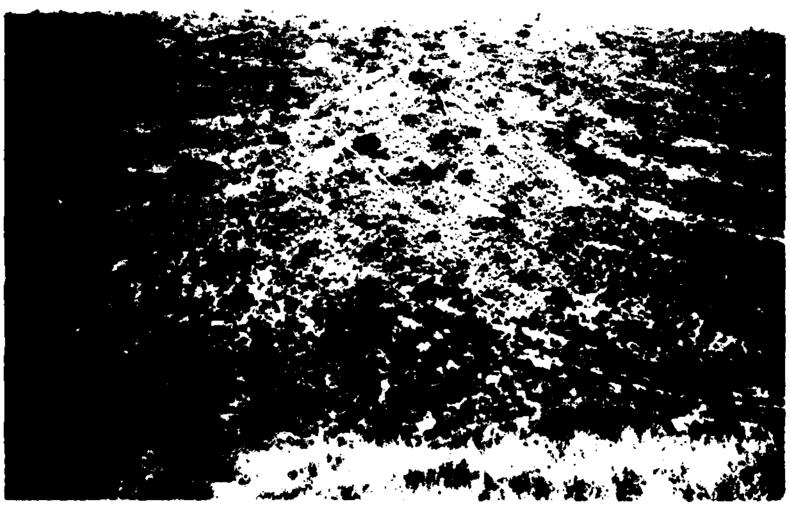


**Figure D14.** Bouteloua curtipendula-Bouteloua uniflora-Parthenium incanum community (16) on dissected limestone hills (Site 291). The land cover is typical of that represented by polygon 12, figure 3 and polygons 1 and 2, figure 5.

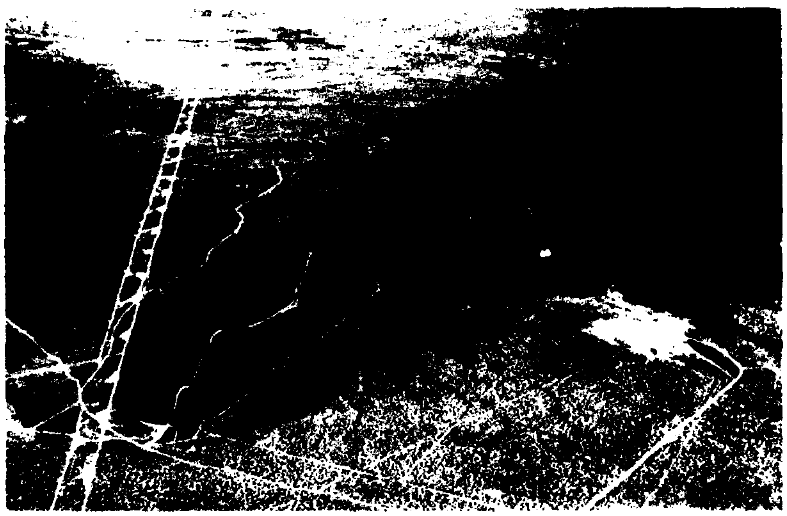


**Figure D15.** Tilted dissected limestone forming the northern portion of the Franklin Mountains. This area corresponds to polygons 11, 12, and 13 in figures 7 and 9. Upper alluvial fans on the left have *Larrea tridentata* community and those on the right and center have *L. tridentata-Prosopis glandulosa* community.

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